

Better Buildings Residential Network Peer Exchange Call Series:

What's Keeping Energy Experts Up at Night? Technical Problems that Need to Be Solved April 11, 2019



Agenda and Ground Rules

- Agenda Review and Ground Rules
- Opening Poll
- Residential Network Overview and Upcoming Call Schedule
- Featured Speakers:
 - Kurt Roth, Fraunhofer USA
 - Curtis Harrington, University of California at Davis
 - Ethan Goldman, OpenEE
- Open Discussion
- Closing Poll and Announcements

Ground Rules:

- 1. Sales of services and commercial messages are not appropriate during Peer Exchange Calls.
- 2. Calls are a safe place for discussion; **please do not attribute information to individuals** on the call.

The views expressed by speakers are their own, and do not reflect those of the Dept. of Energy.





Better Buildings Residential Network

Join the Network

Member Benefits:

- Recognition in media and publications
- Speaking opportunities
- Updates on latest trends
- Voluntary member initiatives
- One-on-One brainstorming conversations

Commitment:

Members only need to provide one number: their organization's number of residential energy upgrades per year, or equivalent.

Upcoming Calls (2nd & 4th Thursdays):

- April 25th: Getting Smarter Every Day: Leveraging Smart Home Technologies to Advance Home Performance Projects
- May 9th: Residential Energy Efficiency in a World of Funding Constraints
- May 23rd: Finding the Balance Between Solar and Energy Efficiency

Peer Exchange Call summaries are posted on the Better Buildings website a few weeks after the call

For more information or to join, for no cost, email bbresidentialnetwork@ee.doe.gov, or go to energy.gov/eere/bbrn & click Join







Kurt Roth Fraunhofer USA

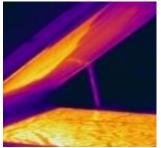


What Keeps Energy Experts Up at Night – One Perspective













Better Buildings Residential Network Webinar

April 11, 2019

Kurt Roth, Ph.D.





What Keeps Me Up at Night: All the poorly insulated, leaky homes!

- Space heating and cooling accounts for ~30% of residential primary energy consumption
- Homes with poor/no insulation and/or high air leakage consume more heating energy
 - → ~20-25 percent of homes have minimal or NO insulation!
 - → Many homes have air-sealing opportunities
- Unrealized Savings from Basic Insulation and Air Sealing: ~\$4-5 billion per year





Sources: DOE/EIA (2009), DOE (2012), DOE/CARB (2017), S. Edwards-Musa, Eversource Energy, Opinion Dynamics (2009).





What Keeps Utility Energy Efficiency Program Administrators up at Night: Low Uptake of proven EE measures

- Slow market uptake of home insulation and air-sealing measures
 - \rightarrow <1% of households/year in Massachusetts (top U.S. EE programs)
- Home Retrofit Program Cost-effectiveness
 - Home energy assessments (HEAs) are costly (\$250-400) and inconvenient
 - Only about 1/3rd of HEAs result in a major retrofit
 - → Customer acquisition cost of ~\$1,000, threatening program cost effectiveness
 - Claimable low-cost lighting savings that support other retrofits are projected to be greatly diminished circa 2020 ("LED cliff")

Sources: Zeifman et al. (2018).





Our Cure for Insomnia:

Project Objective: Develop a tool that analyzes communicating thermostat (CT) data to automatically identify and quantify the benefit of targeted and customized retrofit opportunities

Customer and Utility Benefits:

- Increase the uptake of home energy assessments
- Increase deployment rate of insulation and air-sealing measures
- Decrease the cost of EE programs by targeting customers with opportunities
- Reduce retrofit performance risks using home-level remote EM&V

Ultimate Vision: CTs deployed in most homes identify high-impact opportunities to reduce HVAC energy consumption *and* ensure retrofit performance





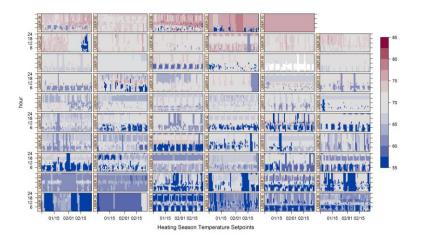
Our tool puts communicating thermostat data to work!

Data we use:

- CT data for a heating season
- Coincident gas bills for 12 months
- Basic building information: conditioned area, # of floors
- ZIP Code

Challenges:

- Missing CT data
- Different CT data formats





Sources: Building36, ecobee, Urban and Roth (2014).

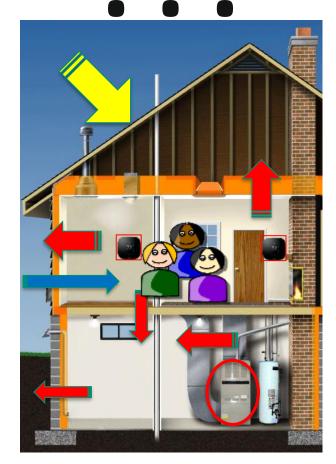




Basic Idea: A home's thermal response reflects its physical characteristics.

Key Challenges

- CT is a point measurement in a home
- Different physical parameters can create similar building thermal responses
- Different HVAC systems have different response times and characteristics
- Many homes have multiple CTs
- Thermal response "noise" from internal heat gains
- Different data from different CT providers



Sources: DOE, Ecobee, Fraunhofer CSE, Wikimedia Commons.





We estimate physical parameters in a 2nd order grey-box model by fitting them to CT data.

$$C_r \frac{dT_r}{dt} = Q_{HVAC} + q_{int} + A_w / (R_w / 2) (T_w - T_r) + q_{inf} \qquad \text{(indoor energy balance)}$$

$$C_w \frac{dT_w}{dt} = A_w / (R_w / 2) (T_r - T_w) + A_w / (R_w / 2) (T_a - T_w) + q_{ext} \qquad \text{(enclosure energy balance)}$$

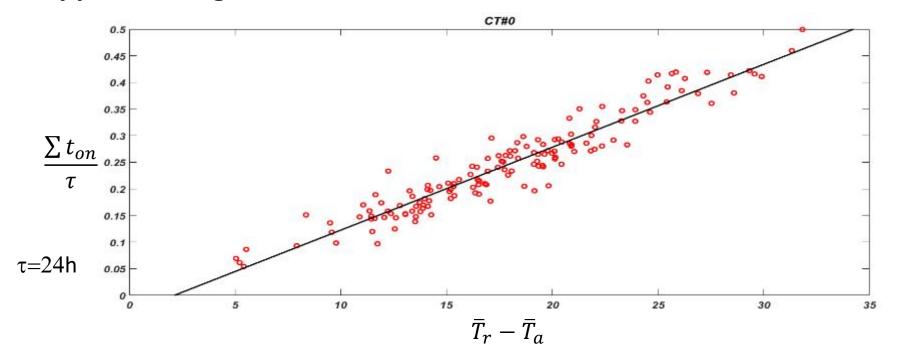
$$q_{inf} = -\rho_{air} c_{p,air} (C_1 W^{2.6} + C_2 | T_a - T_r|^{1.3})^{0.5} (T_r - T_a) \qquad \text{(from I. Walker)}$$

- = known, = prediction needed for home assessment
- $T_{\mathbf{r}}$, $T_{\mathbf{w}}$, $T_{\mathbf{a}}$ = indoor, enclosure (wall) and outdoor temperatures
- \blacksquare and $\frac{A_w}{A_w}$ = overall R-value and area of building envelope
- C_w and C_r = overall heat capacitance of the walls/internal space (=external/internal thermal mass)
- Q_{HVAC} = HVAC heat supply
- $= q_{int}/q_{ext}/q_{inf}$ = internal/external heat gains /infiltration heat loss
- w = wind speed, C₁, C₂ coefficients
- Isolates infiltration from R-value assessment





Approach: High-resolution PRISM model for each home



■ PRISM: (fuel billed) × $\eta = (\overline{conduction} + \overline{infiltration}) \times (\overline{T_r} - \overline{T_a}) - \overline{heat\ gains})$

$$\frac{\sum t_{on}}{\tau} = \left[\frac{A_w}{R_w Q_{hvac}} + \sqrt{\left(\frac{\rho c_p}{Q_{hvac}}\right)^2 C_1 \overline{W}^{2.6} + \left(\frac{\rho c_p}{Q_{hvac}}\right)^2 C_2 |\overline{T}_r - \overline{T}_a|^{1.3}} \right] (\overline{T}_r - \overline{T}_a) - \frac{q}{Q_{hvac}}$$

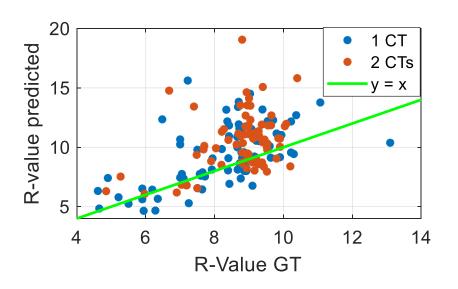
- Sacrifice: heating system efficiency, η (assume ~80%)
- Can predict runtime and future savings from retrofits, and perform EM&V

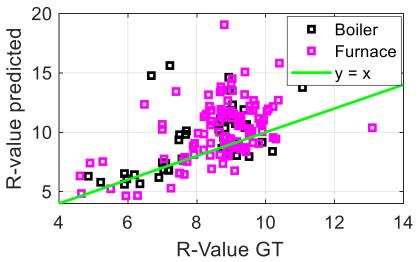
Sources: Fels (1986).





Results: The tool accurately classifies whole-home R-value.





Results by number of CTs

Results by heating system type

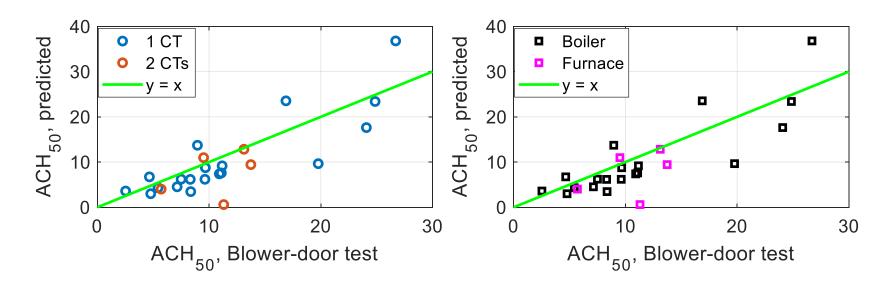
Classification Accuracy (R>8 or ≤ 8) = 89% (n=154)

(ground truth derived from home energy assessments)





Results: The tool accurately classifies ACH₅₀.



Results by number of CTs

Results by heating system type

Classification Accuracy (ACH₅₀ > 15 or \leq 15) = 96% (n=24)

(ground truth from blower-door tests)





Remaining Project Work: Validation to Scale

Randomized Controlled Trial (RCT) Research Questions: Does reaching out to customers with specific ECMS and predicted savings increase:

- Home Energy Assessment (HEA) uptake
- 2. Uptake of energy conservation measures

Randomized Controlled Trial (RCT) Design

Group Type	Description	Additional Outreach?	N (approx.)
Control	1. CT incentive, have CT data	Generic outreach.	700
	2. CT incentive, other CT type	None.	1,000
	3. No CT incentive	None.	1,000
Treatment	1. CT incentive, have CT data	Customized outreach	250



Acknowledgements

- Fraunhofer
 - Michael Zeifman
 - Amine Lazrak
- Funding:
 - U.S. DOE Building America Program
 - Eric Werling
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- Eversource:
 - Brian Greenfield
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 - Peter Kuhn
- National Grid:
 - Brenda Pike
 - Cassandra Vickers
 - Rick Wester









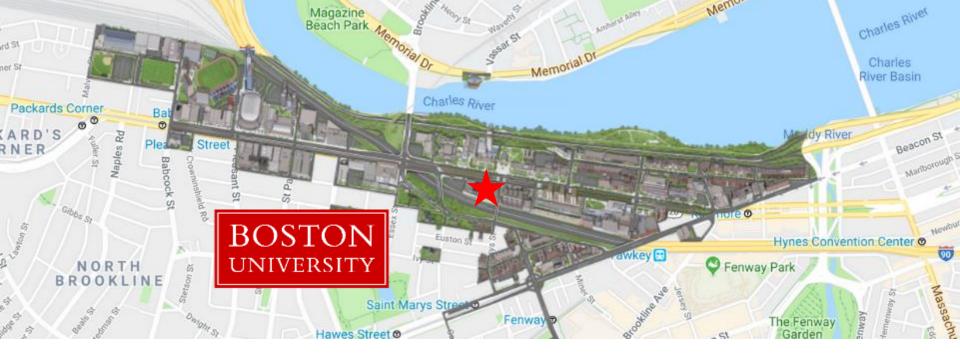






Bringing Housing Innovations to Market





Contact

Kurt Roth, PhD

kroth@fraunhofer.org

+ 1 617 353-1895

15 Saint Mary's Street

Brookline, MA 02446





Key Points

- Basic insulation and air sealing could save homeowners up to \$5 billion annually
- Uptake of residential upgrades is poor, with only 1/3 of projects constituting a "major" upgrade
- Fraunhofer and Building America successfully demonstrated the use of communicating thermostat data to estimate a home's efficiency







Curtis Harrington UC Davis







BBRN Peer Exchange: What's Keeping Energy Experts Up at Night? Technical Problems That Need to Be Solved

System Efficiency vs. Equipment Efficiency

Curtis Harrington April 11, 2019















Next Generation Heat Pump Testing

UC Davis Project for Electric Power Research Institute

Sponsored by California Energy Commission

Three-phase project

- Variable-speed, single-zone lab testing
- Variable-speed, multi-zone lab testing
- Field testing

UC Davis Objectives

- Lab Testing of variable capacity equipment
 - Impact of duct system in unconditioned space
 - Impact of zoning controls
- Develop/test model of equipment and ducts





UC Davis Lab Testing – Includes Ducts

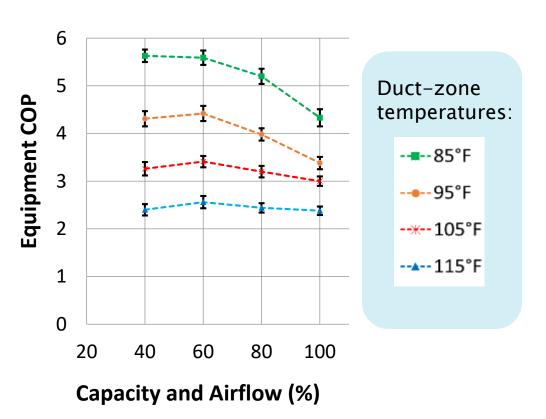


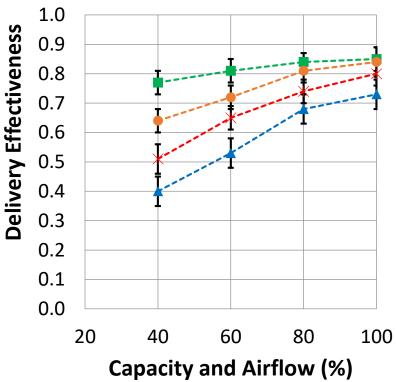
- Actual duct design for a 2-ton single-family system
- Standard new-construction duct insulation R-6
- No duct leakage





Equipment COP and Duct Efficiency vs. Compressor and Fan-Speed





Equipment performance increases as speed is reduced

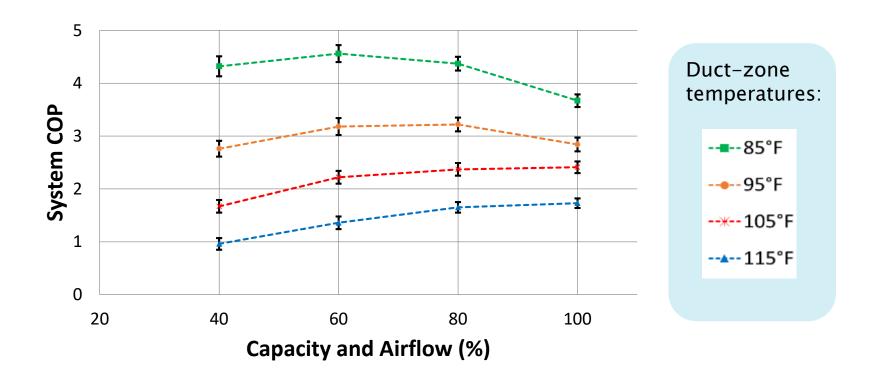
Delivery effectiveness decreases as speed is reduced





System COP

- System COP = Equipment COP x Delivery Effectiveness
 - System COP describes overall efficiency including equipment and ducts
- Maximum System COP depends on outdoor/attic temperature



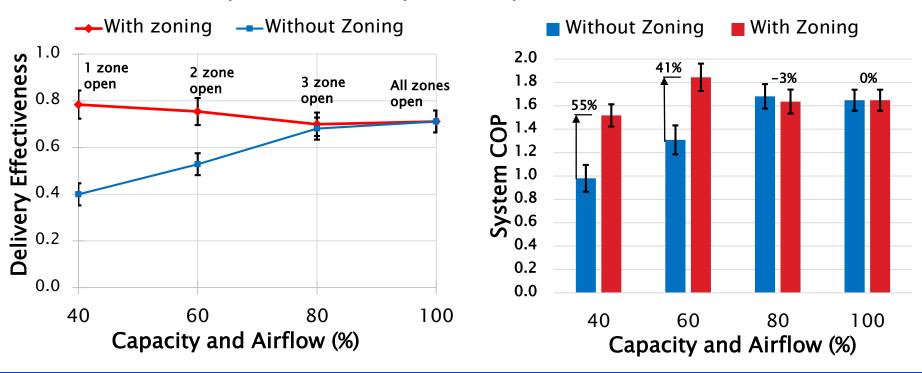
Optimal speed at high temperatures is 100%





Impact of Adding Zoning: (Attic: 115°F, Indoor: 75°F)

- 95% more cooling delivered when zoned at low speed
- 40–55% better system efficiency at low speed



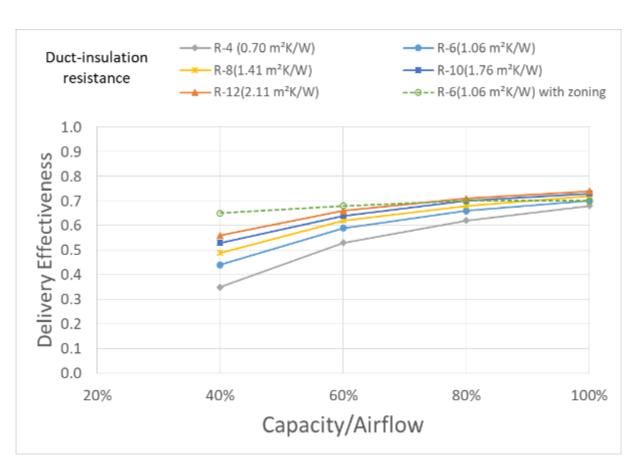
Zoning can significantly reduce duct losses at low speed





Zoning versus Adding Insulation: (Attic: 115°F, Indoor: 75°F)

- R-6 with zoning had best performance
- All had similar effectiveness at high speed
- R-12 had 20% higher effectiveness than R-4 at low capacity





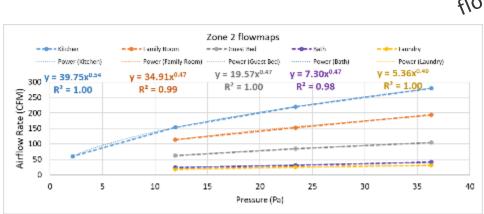


Field Evaluation of Duct Losses

- Delivery effectiveness for each grill monitored
 - Temperature at each grill
 - Temperature/Relative Humidity at equipment
 - Airflow mapped for each grill
 - Indoor and outdoor unit power



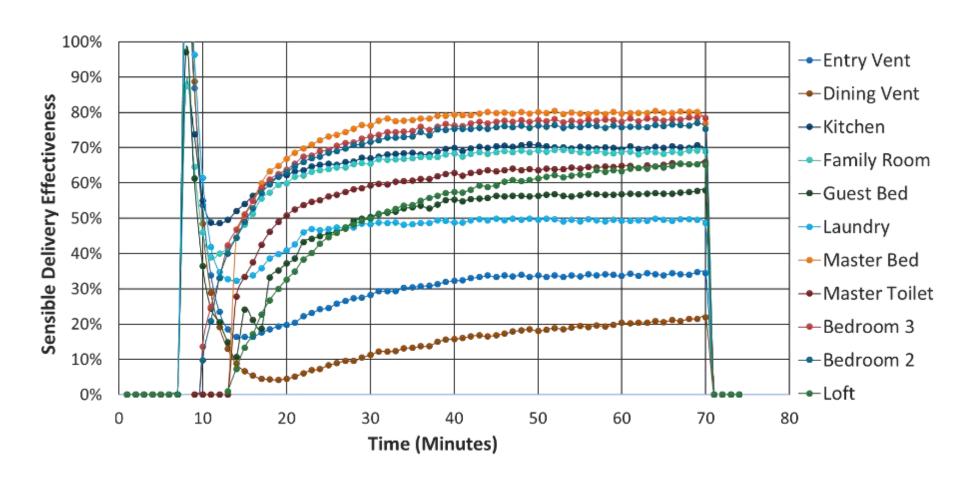








Delivery Effectiveness for Each Grill



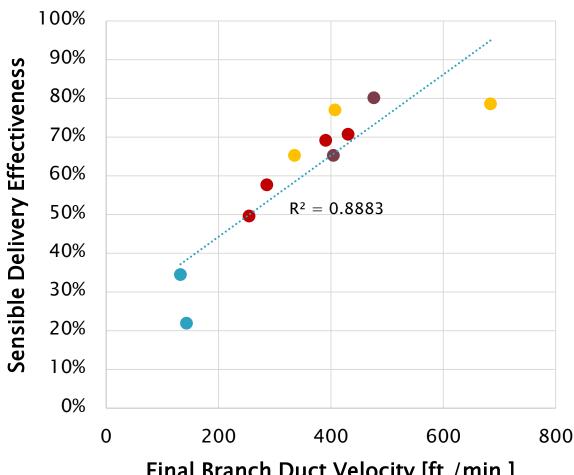
Delivery effectiveness varies between grills and ranged from 20-80%





Impact of Duct Velocity and Delivery Effectiveness

- Velocity is good indicator of effectiveness
- Lower velocity resulted in lower effectiveness
- Typical max velocity in res. = 600 ft/min



Final Branch Duct Velocity [ft./min.]

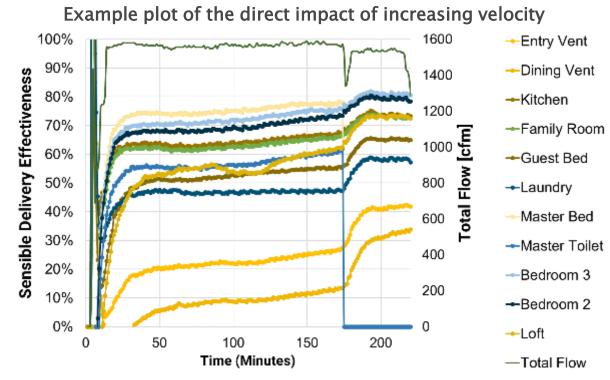
50% reduction in fan speed results in only 30% reduction in delivered capacity





Higher Velocity Resulted in Higher Delivery Effectiveness

- Zone 3 closed (Master Bed, Master Toilet) at ~175 minutes
- Airflow stayed relatively constant
- Remaining active grills had an increase in delivery eff.
 - 25% increase in velocity
 - 10% increase in delivery effectiveness







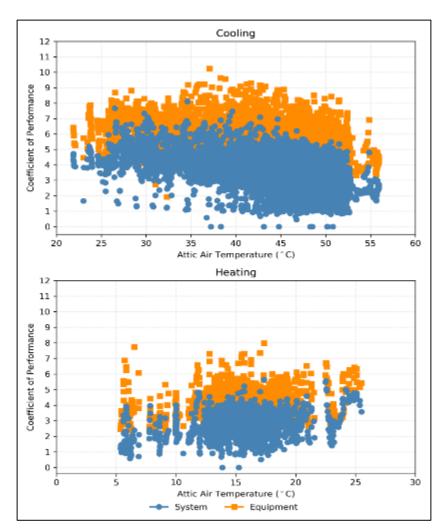
Equipment and System COP (SDG&E)

Cooling Data

- Average Equipment COP = 5.2
- Average System COP = 3.4
- Delivery Effectiveness = 65%

Heating Data

- Average Equipment COP = 3.8
- Average System COP = 2.6
- Delivery Effectiveness = 68%



Delivery effectiveness was good but not optimal





Next Generation Heat Pump Testing Where will this land?

UC Davis Predictions

Variable-speed systems have tremendous possibilities:

- Allow control of ratio of cooling and dehumidification
- Ducts significantly impact variable-speed equipment
- Duct location and insulation will impact choice of control algorithms

Best Solution: Variable-speed systems with zoning

- Combination address equipment/duct interactions
- Facilitates energy-efficient demand response programs
- Increased duct insulation can also reduce equipment/duct interactions





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Key Points

- UC Davis undertook a research project to understand how duct design can impact energy consumption
- Variable-speed systems combined with zoning delivered appreciable savings
- It was found that higher system velocity resulted in increased performance







Ethan Goldman OpenEE

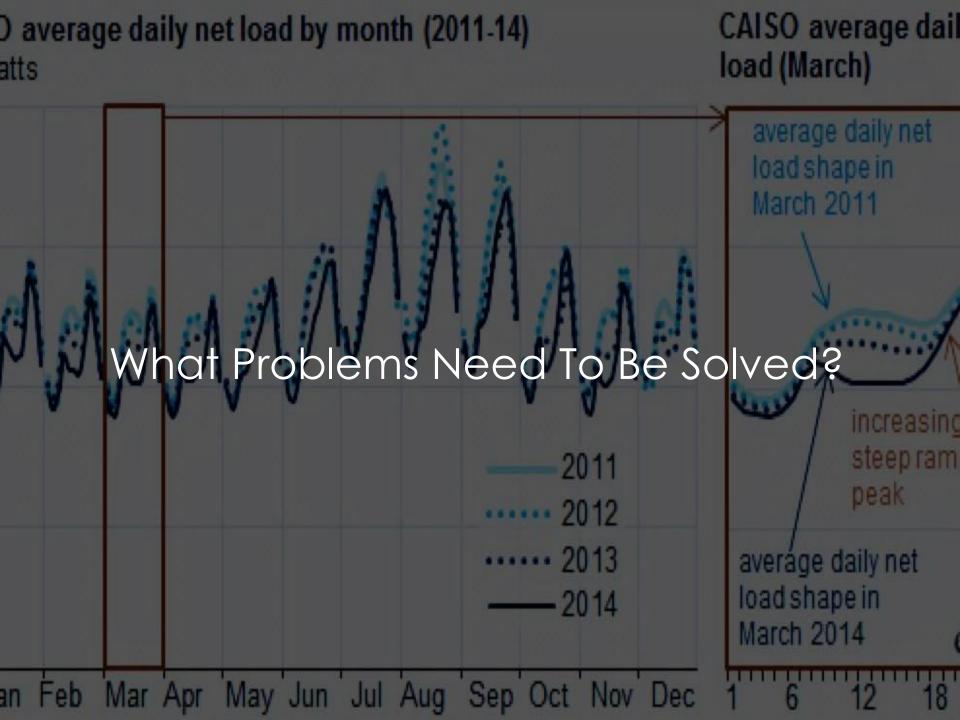




How Does Flexible Demand Become a Grid Resource?

Efficiency, Demand Response, and Electrification

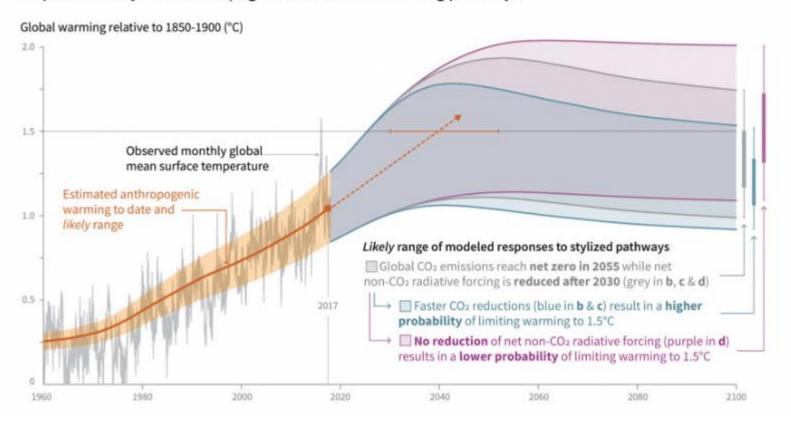
Ethan Goldman, Director of Customer Solutions for OpenEE ethan@openee.io



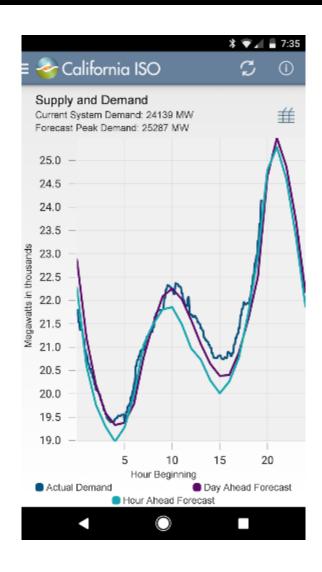
IPCC: 12 Years to Fight Climate Change

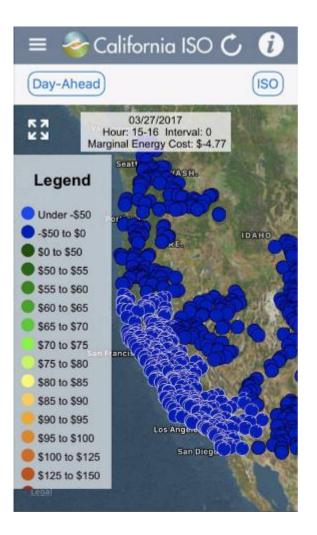
Cumulative emissions of CO₂ and future non-CO₂ radiative forcing determine the probability of limiting warming to 1.5°C

a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways

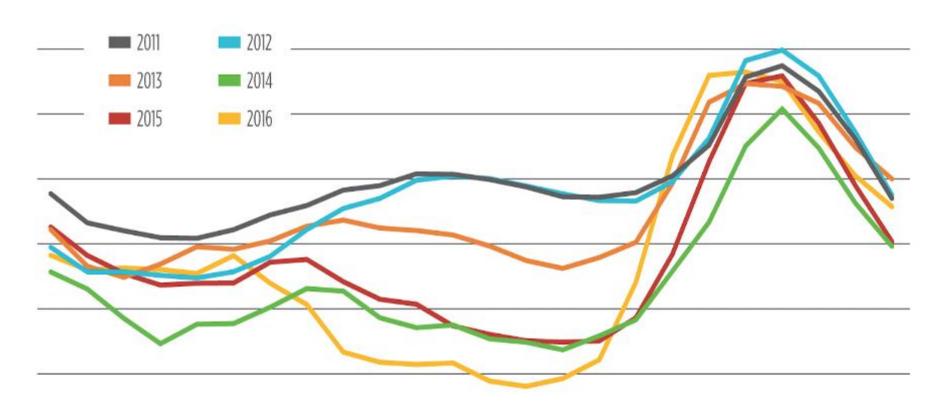


Lots of Renewables But No Place To Put Them



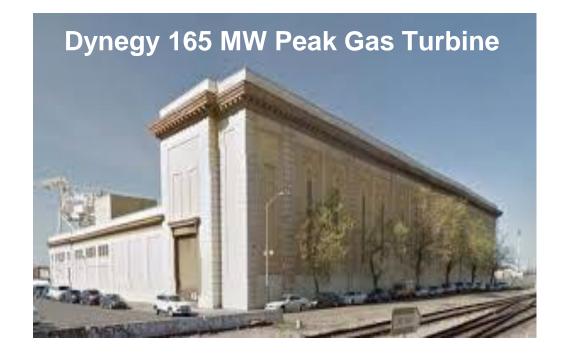


The Big Bad Duck

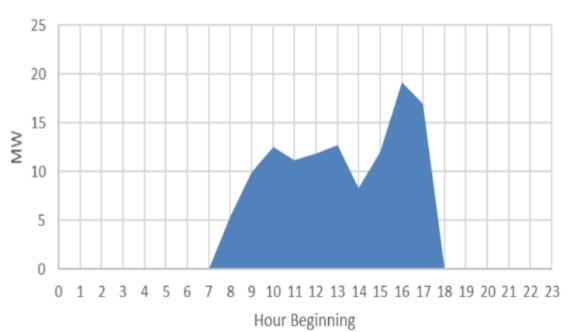


Four Years Ahead of CAISO Projections

Oakland Clean Energy Initiative



OCEI Peak Day Hourly Resource Need







- Standard Calculation Methods for Energy Efficiency and Electrification
- Monthly, Daily, and Hourly
- Public 60 Stakeholders Empirical Process
- www.CalTRACK.org



- Python CalTRACK Engine
- Open Source <u>Apache 2.0</u>
- Available Without Restriction
- How It Works: https://goo.gl/mhny2s
- Code Repo: https://goo.gl/qFdW4P





AHUP vs. Commercial Deemed



Not All EE is of Equal Value

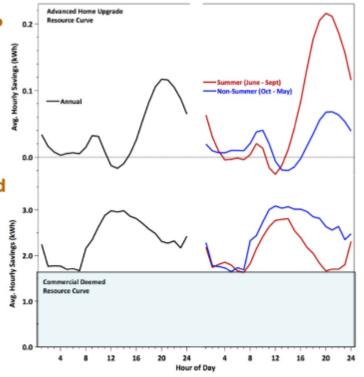
AHUP

AHUP Savings more variable by time and season

Commercial Deemed

High portion of AHUP savings during summer peak hours

Comm Deemed: Baseload (24 x 7) savings









T&D, Energy, Capacity, Carbon

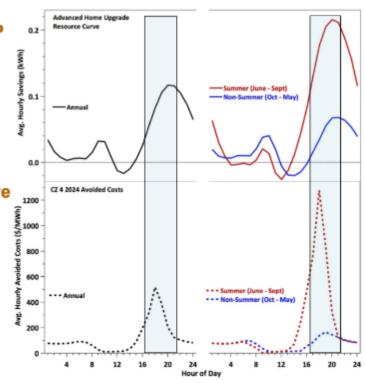


AHUP savings largely during peak. Targeting can enhance further.

Avoided Cost Curve (CZ 4, 2024)

More grid-aligned locational avoided costs needed

3x P4P kicker for summer peak savings!





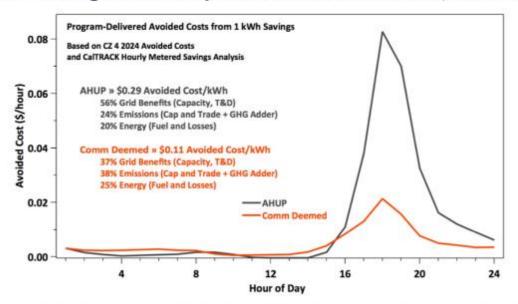
What is EE Really Worth?



Putting it Together



Benefits = Savings Load Shape x Avoided Cost Curve (8760 Basis)



- High portion of benefits from avoided "grid" costs (capacity, T&D)
- Comm Deemed: 6% savings during summer peak = 37% of avoided costs; 30% of savings from 8 am 3 pm = 5% of avoided costs

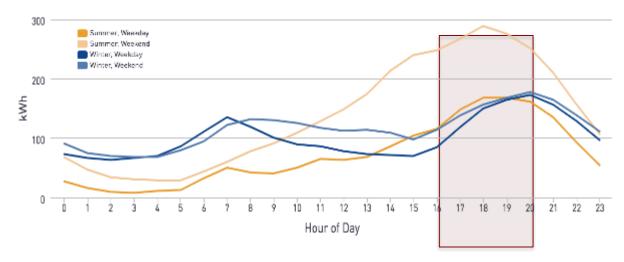


RESOURCE CURVE

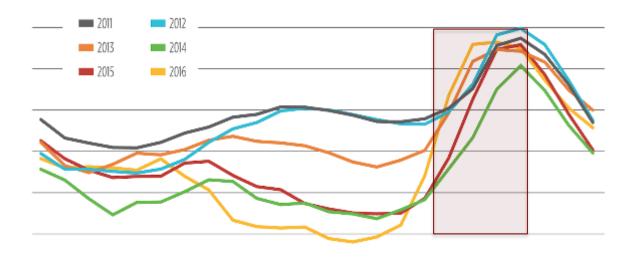
Time And Locational Savings

Resource Curve

Resource Curve by Season and Weekend/Weekday



Duck Curve



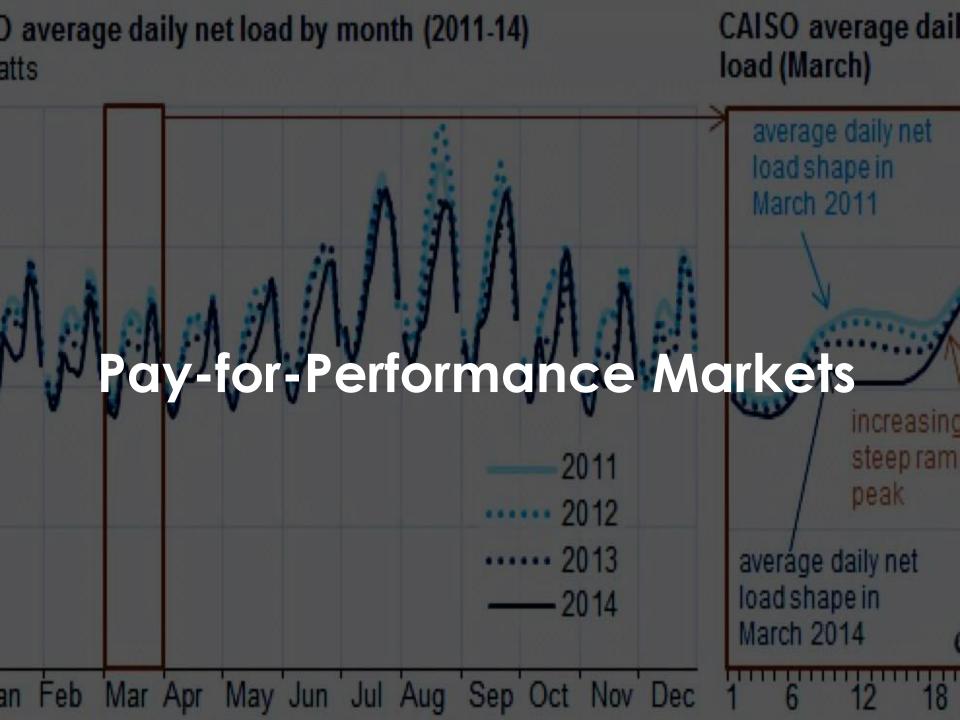




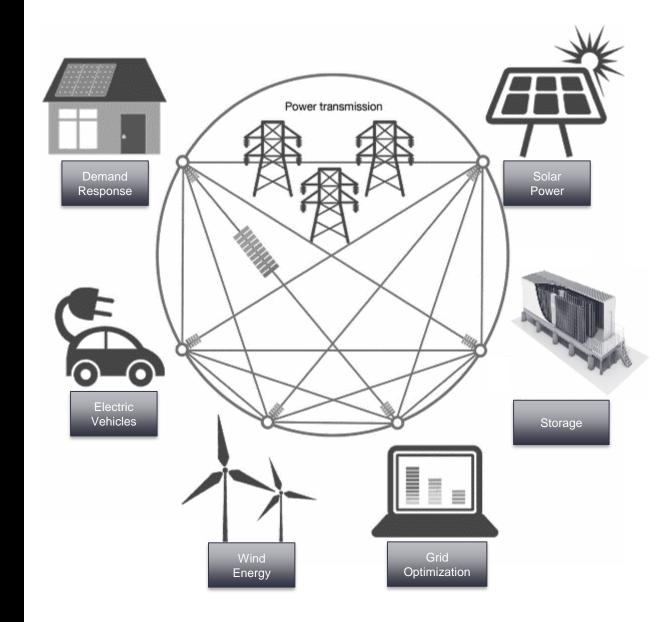
On-peak and Off-peak Energy or Carbon Savings



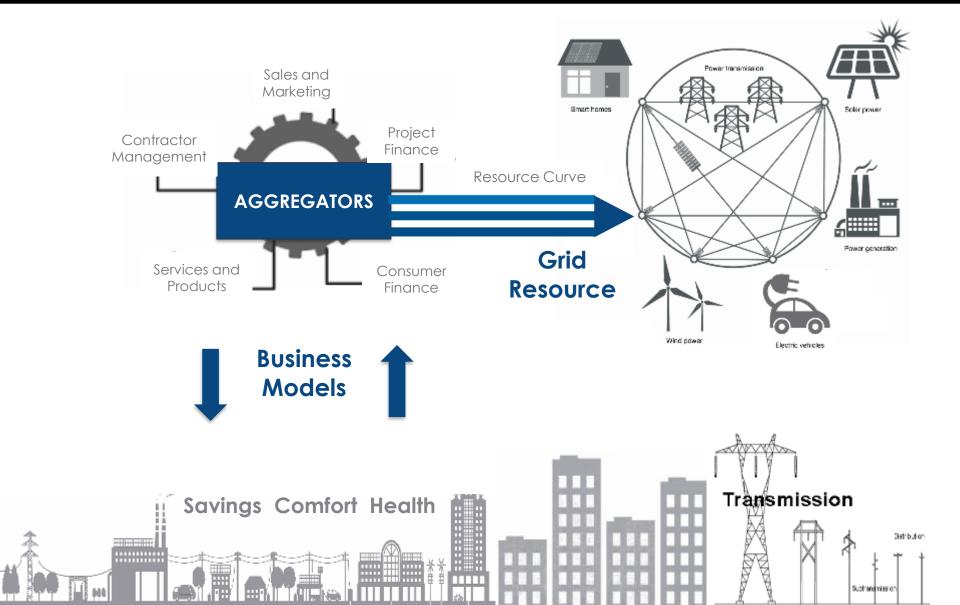
Are savings happening at the targeted times and locations and what are the marginal GHG impacts?



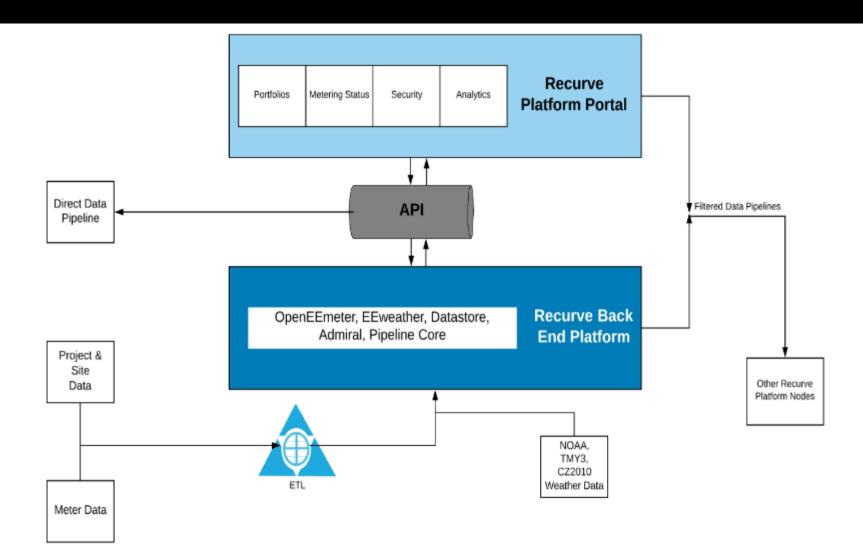
Fitting
Flexible
Demand into
Distributed
Energy
Resource
Markets



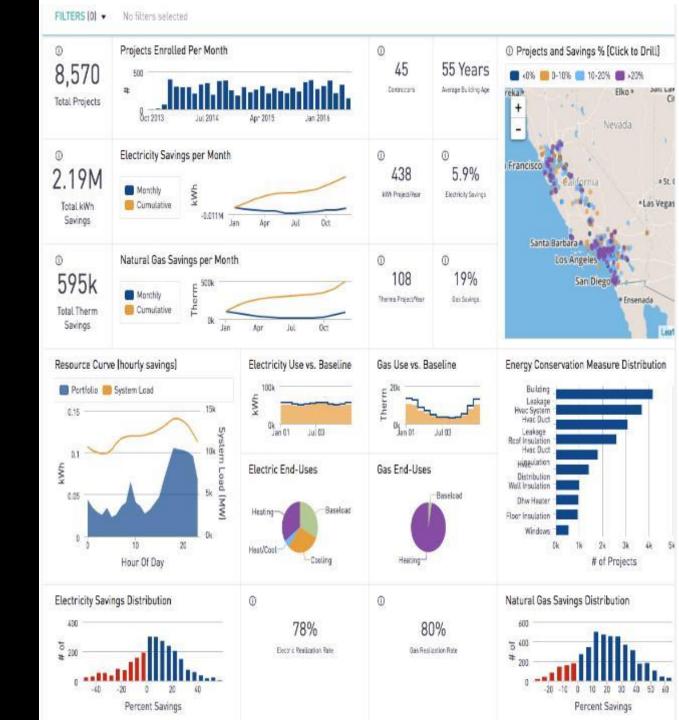
Align Incentives with Pay-for-Performance







Track Your Projects and Performance

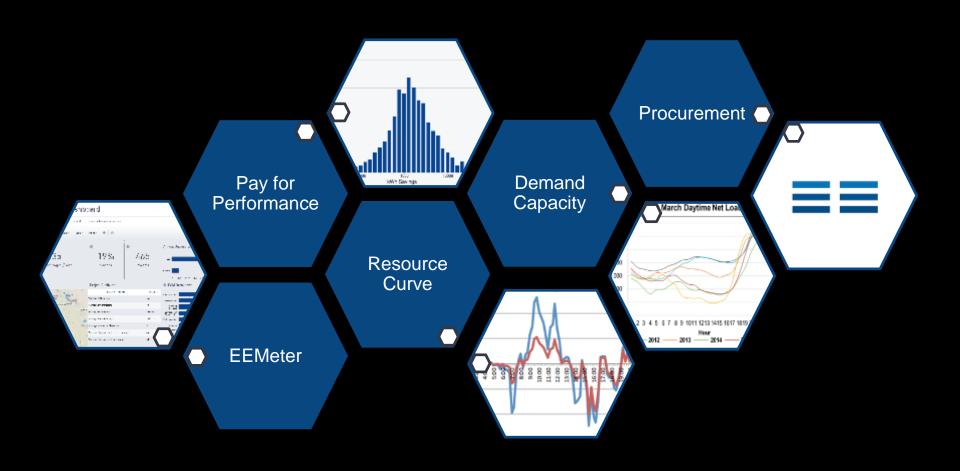


Target and Qualify Customers



Roadmap to flexible demand markets





Ethan Goldman, Director of Customer Solutions ethan@openee.io

Key Points

- Not all energy efficiency is equivalent in value
- Energy savings during times of peak demand are significantly more impactful
- Tools such as those produced by Open EE allow utilities to better understand the distribution of storage and generation capacity in order to align incentives





Register for the Better Buildings Summit



- **WHEN**: July 10-11, 2019
- WHO: Better Buildings partners & stakeholders, & ~200 speakers with proven solutions
- WHAT: 2 days of sessions, networking, & sharing the most successful energy efficiency strategies
- WHERE: Arlington, VA across from Washington D.C.
- INFO: energy.gov/betterbuildings/summit

It only happens once a year





Explore the Residential Program Solution Center

Resources to help improve your program and reach energy efficiency targets:

- Handbooks explain why and how to implement specific stages of a program.
- Quick Answers provide answers and resources for common questions.
- Proven Practices posts include lessons learned, examples, and helpful tips from successful programs.
- Technology Solutions NEW! present resources on advanced technologies, HVAC & Heat Pump Water Heaters, including installation guidance, marketing strategies, & potential savings.



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